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Investigating the Impact of Different Postharvest Treatments on Shelf-Life Extension and Quality Attributes of Banana

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The banana (*Musa sapientum*) ranks as the fourth most important fruit crop in the world and is widely grown in tropical and subtropical regions. It contains carbohydrates, fiber, protein, vitamin B2, vitamin B3, vitamin C, fat, phosphorus, calcium, iron, and ß-carotene. However, despite the crop's high nutritional value and growing demand, commercial cultivation is challenged by the lack of efficient postharvest storage facilities. This study aimed to investigate the impact of different postharvest treatments on the shelf-life extension and quality attributes of banana, and the physicochemical changes during storage and ripening. The present study consisted of five treatments including T_0 (control), T_1 (Fungicide; Dithane 0.2%), T_2 (Hot Water; 55°C), T_3 (Calcium Chloride; 2%), and T_4 (Calcium Chloride; 4%). Physicochemical analysis including total soluble solids (TSS), pH, and total titratable acidity (TTA) was done to monitor the banana's shelf-life extension. The phytochemical analysis includes total phenolic content, and microbial analysis includes total plate count, disease incidence, and disease severity was determined at an interval of 5 days to evaluate for the period of 15 days. The highest pH was observed at 6.43±0.04 for T_0, the highest total soluble solids were observed at 4.5±0.1 for T_4, and the highest titratable acidity was 0.47±0.03 for T_4. The highest total phenolic content was observed at 151.2±0.04 and the highest firmness was observed at 6.00±0.9 for T_4, and the lowest total plate count was showed at 3.3±0.2 in T_1. The lowest disease incidence and disease severity were observed in T_1 at 12.56±0.01 and 1.02±0.02 respectively. Sensory analysis was conducted using 9-point hedonic scale to evaluate consumer acceptance.

Keywords: Nutritional composition, postharvest loss, ripening, respiration rate, organoleptic assessment.

INTRODUCTION

Banana (*Musa sapientum*) is the most grown food crop in tropical and subtropical regions of the world. Banana is a member of the *Musaceae* family and is the largest among flowering herbaceous plants. There are around 40 species in the genus Musa, most of which are likely to have originated in Assam, Myanmar, or Thailand. Based on the gross production value, bananas rank as the fourth most important food commodity worldwide, after rice, wheat, and maize. It is a popular, tasty, healthy, and reasonably priced table fruit that is consumed at a higher rate in Bangladesh than any other fruit. It is a rich source of carbohydrates, fiber, protein, fat, phosphorus, calcium, iron, ß-carotene, Vitamin B_2, vitamin B_3, and vitamin C (Aziz *et al.*, 2021).

A banana contains five times more vitamin A and iron, four times more protein, three times more phosphorus, two times more carbohydrates, and other vitamins and minerals as compared to an apple which makes banana unique in terms of calories and nutritional content. Because of its high nutritional and caloric content, people are consuming more bananas to boost their metabolism and improve their heart health. However, the lack of postharvest storage facilities has become a major threat to the commercial cultivation of bananas (Das *et al.*, 2021).

A ripened banana provides instant energy, readily digested, and is useful as a medicinal fruit. It helps in reducing the risk of anemia, hypertension, cancer, depression, ulcers, constipation, etc. Now a day, malnutrition is a serious issue affecting people's physical, mental, and financial growth in developing nations. The most severe nutritional deficiencies among low-income groups are protein-energy malnutrition and vitamins deficiency. Underweight, wasting and stunting are the most common types of malnutrition in infants and preschoolers that ultimately compromise the overall health of young people in their later years. The minimal dietary requirement of banana for each person is about 115 g, while

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our availability is only about 30-35 g (Amin and Hossain, 2012).

A banana's propensity for rapid ripening and texture breakdown makes it challenging to store for a prolonged period. Many farmers have tried to increase the shelf life of bananas by applying different substances before and after harvest. Banana needs to have an extended shelf life and fewer postharvest diseases to meet export quality standards while being transported abroad and to be stored for marketing. As most synthetic chemicals used for crop protection have residual effects and pose serious risks to human health, as a result, all these elements have led to find safer and more cost-effective alternatives to improve the shelf life of bananas (Hosseini *et al.*, 2018).

With the proper postharvest handling, the quality of fruits is maintained until they are consumed. Banana postharvest management involves harvesting the fruit at the proper mature stage, removing field heat as soon as possible using suitable pre-cooling techniques, and applying fungicides, growth regulators, and growth inhibitors after harvest. Moreover, the use of appropriate packaging and storage techniques for both short as well as long-distance transportation are also involved in postharvest management. The higher the storage temperature, the higher will be the banana's respiration rate, which affects the transportation and postharvest life of the banana (Ravikumar *et al.*, 2018). Research on the effects of the chemical concentrations and possible synergistic use of advanced storage techniques is lacking in literature as substantial research has been conducted on either the changes in the physicochemical properties during storage or the effectiveness of the specific treatment methods separately.

This research study seeks to fill these gaps by comparing the effects of various post-harvest treatments and their concentration on the shelf life and quality of bananas. Specifically, the fungicides, hot water, and calcium chloride treatments were investigated in terms of the treatments' effect on quality attributes to present workable and technically feasible approaches to minimize postharvest losses. The results of this research proved very useful to farmers, fruit exporters, and consumers on a global level by increasing knowledge on the cost-efficient ways of increasing shelf life of bananas. The present study was aimed at exploring the following objectives:

- To check the impact of different postharvest treatments on the quality attributes of banana
- To check the impact of different postharvest treatments on the shelf-life extension of banana

MATERIALS AND METHODS

***Procurement of raw material*:** Banana bunches were procured from the local market of Faisalabad and stored at room temperature.

***Preparation of raw material*:** Banana bunches were cooled with a fan for 30 minutes to get rid of the field heat. Matured bananas of approximately the same size, shape, and color were chosen. Banana skin was cleaned with soft tissue paper to remove dirt, dust, and debris.

***Postharvest treatments*:** The bananas were subjected to different postharvest treatments. The study consisted of four treatment groups while the first one was the control group (untreated).

Table 1. Treatment plan.

Treatments	Application	Conditions
T_0	-	-
T_1	Fungicide	0.2% for 2 min
T_2	Hot Water	55°C for 2 min
T_3	$CaCl_2$	2% for 2 min
T_4	$CaCl_2$	4% for 2 min

Note: The storage study of 15 days was done at an interval of 5 days. While T_0=(control); T_1=(Fungicide; 0.2%); T_2=(Hot Water; 55°C); T_3=(Calcium Chloride; 2%); T_4=(Calcium Chloride; 4%)

Physicochemical analysis

***pH*:** The pH was calculated using a pH meter according to the protocol followed by AOAC (2023). Electrodes of the pH meter were calibrated by using the buffer solution of pH 7.

***Total Titratable Acidity*:** Total titratable acidity (TTA) was assessed according to protocols followed by AOAC (2023).

***Total Soluble Solid*:** Total soluble solid (TSS) was calculated according to the procedure followed by AOAC (2023). Reading was taken of each sample and recorded in form of °Brix.

***Firmness*:** A banana firmness tester was used to determine firmness. Firmness was calculated according to the procedure followed by Kumar *et al.* (2019).

Phytochemical analysis

***Total Phenolic Content*:** Total phenolic content (TPC) was assessed using the Folin-Ciocalteu reagent. The method of Minh (2022) was used for assessing the total phenolic contents of banana fruit. The total phenolic contents of banana fruit were expressed as mg GAE 100 g FW by using gallic acid as standard.

Microbial analysis

***Total Plate Count*:** Total plate count (TPC) was analyzed by calculating the total CFU under a microscope by using an appropriate formula followed by Bazaz *et al.* (2018). This

method involves culturing bacteria from fruit sample on nutrient agar plates and counting the resulting colonies to estimate the number of viable microorganisms.

***Disease severity*:** An assessment of disease severity is based on the percentage of bananas that are infected with the disease. To check whether the fruit area is infected, one banana was chosen from each replication and was observed visually. Disease severity was expressed in scores ranging from 1-5 (1 = none, 2 = 1-3%, 3 = 4-6%, 4 = 7-15%, 5 = >30, fruit covered with symptoms of disease). This visual interpretation was assessed using scores mentioned on the scale, followed by Rajwana *et al.* (2011).

***Disease incidence*:** Disease incidence means the percentage of fruits infected with diseases. All the bananas from each replication were visually checked for decay symptoms at every 5-day intervals. Any fruit showing rotting symptoms was considered decayed fruit. Disease incidence was expressed in percentage by using a formula according to the method followed by Rubel *et al.* (2019).

$$\text{Disease Incidence (\%)} = \frac{\text{Number of decayed bananas}}{\text{Total number of bananas}} \times 100$$

***Sensory evaluation*:** Sensory evaluation was carried out based on color, flavor, texture, and overall acceptability using a 9-point hedonic score system followed by Meilgaard *et al.* (2016). Evaluation was done by senior students of NIFSAT by using evaluation performa. The score from each panelist for every parameter was recorded. These scores were later used to carry out statistical analysis.

Statistical analysis: The obtained data was analyzed using a completely randomized design (CRD) to determine the level of significance and a comparison of means according to the method as described Montgomery (2017).

RESULTS

Physicochemical analysis

***pH*:** Storage days and treatments significantly affected the pH of the stored banana fruit. The mean values of pH on treatment and storage of banana fruit have been given in Table. Hence, the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 4.61±0.02-6.43±0.04. A significant difference was observed between the control and treated samples. Control treatment shows higher values of pH compared to all other treated samples. The pH value in treatment T_3 and T_4 was almost maintained during 15 days of storage. An increasing trend in pH values was observed in all treatments during storage.

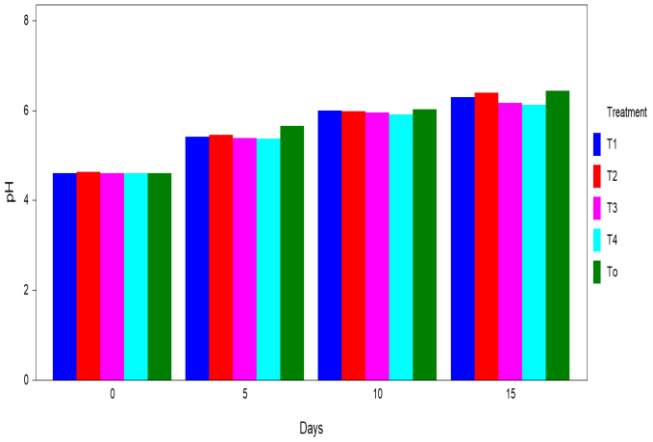

Figure 1. Effect of postharvest treatments on pH of banana.

***Titratable acidity*:** The effect of treatment, days, and their interaction on the fruit quality was significant. The mean values of titratable acidity on treatment and storage of banana fruit have been given in Table. Hence, the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 0.47±0.03-0.7±0.02. A significant difference was observed between the control and treated samples. Less reduction in titratable acidity was observed in T_3 and T_4 during 15 days of storage. Titratable acidity (TA) showed a decreasing pattern during the 15 days of storage.

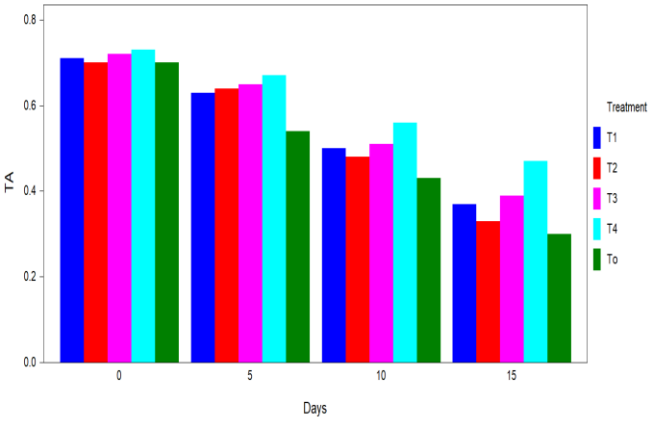

Figure 2. Effect of postharvest treatments on Titratable acidity of banana.

***Total soluble solids*:** The effect of treatment, days, and their interaction on the TSS of banana was significant. The mean values of total soluble solids on treatment and storage of banana fruit have been given in Table. Hence, the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 5.9±0.2-13.8±0.3. A significant difference was observed between the control and treated samples. Less reduction in total soluble solids was observed in T_4 during 15 days of storage. The maximum amount of total soluble solids (TSS) was observed in control (13.8±0.3) and the minimum value for TSS was observed in T_4 (5.9±0.2). Total soluble solids increased with the increase in storage time.

Table 2. Means for physicochemical analysis of banana fruit during storage.

	Treatments	Storage Intervals (Days)				Means
		0 days	5 days	10 days	15 days	
pH	T_0	4.61±0.02	5.65±0.02	6.02±0.04	6.43±0.04	$5.67±0.70^{A}$
	T_1	4.61±0.09	5.41±0.01	6±0.05	6.3±0.3	$5.58±0.68^{BC}$
	T_2	4.63±0.02	5.45±0.06	5.98±0.04	6.39±0.02	$5.61±0.68^{AB}$
	T_3	4.61±0.03	5.39±0.01	5.95±0.04	6.16±0.02	$5.52±0.62^{BC}$
	T_4	4.61±0.05	5.37±0.02	5.91±0.01	6.13±0.05	$5.50±0.61^{C}$
	Means	$4.61±0.02^{D}$	$5.45±0.02^{C}$	$5.97±0.01^{B}$	$6.28±0.12^{A}$	
Titratable acidity (%)	T_0	0.7±0.02	0.54±0.01	0.43±0.02	0.3±0.02	$0.49±0.15^{C}$
	T_1	0.71±0.03	0.63±0.05	0.50±0.04	0.37±0.04	$0.55±0.13^{B}$
	T_2	0.7±0.01	0.64±0.02	0.48±0.03	0.33±0.04	$0.53±0.15^{B}$
	T_3	0.72±0.02	0.65±0.05	0.51±0.01	0.39±0.04	$0.56±0.13^{B}$
	T_4	0.73±0.02	0.67±0.05	0.56±0.04	0.47±0.03	$0.60±0.10^{A}$
	Means	$0.71±0.00^{A}$	$0.62±0.01^{B}$	$0.49±0.01^{C}$	$0.37±0.00^{D}$	
Total soluble solids (°Brix)	T_0	5.9±0.2	7.1±0.1	9.8±0.3	13.8±0.3	$9.22±3.29^{A}$
	T_1	5.9±0.2	6.8±0.2	8.8±0.1	11.9±0.1	$8.35±2.40^{BC}$
	T_2	5.9±0.2	7.1±0.2	8.9±0.4	12.45±0.2	$8.58±2.58^{B}$
	T_3	5.9±0.4	7±0.1	8.75±0.2	11.5±0.5	$8.28±2.22^{C}$
	T_4	5.9±0.6	6.7±0.3	8.51±0.2	10.85±0.4	$7.99±2.00^{D}$
	Means	$5.90±0.17^{D}$	$6.94±0.08^{C}$	$8.95±0.11^{B}$	$12.16±0.15^{A}$	
Firmness (Kgf)	T_0	8.15±0.1	6.99±0.8	5.34±0.11	3.21±0.11	$5.92±1.97^{B}$
	T_1	8.18±0.1	7.46±0.13	5.85±.0.8	3.45±0.1	$6.23±1.92^{B}$
	T_2	8.18±0.12	7.17±0.9	5.66±0.11	3.30±0.8	$6.06±1.98^{B}$
	T_3	8.15±0.9	7.76±0.9	7.35±0.12	5.81±0.1	$7.31±1.01^{A}$
	T_4	8.18±0.11	7.93±0.13	7.53±0.1	6.00±0.9	$7.46±0.88^{A}$
	Means	$8.16±0.35^{A}$	$7.45±0.32^{B}$	$6.34±0.30^{C}$	$4.43±0.41^{D}$	

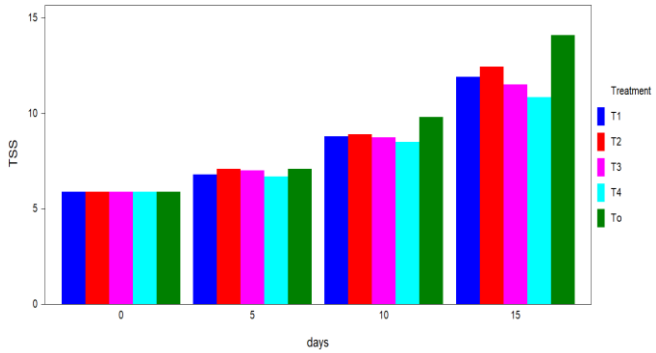

Figure 3. Effect of postharvest treatments on TSS of banana.

***Firmness*:** The mean values of firmness on treatment and storage of banana fruit have been given in Table. Hence the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 8.18±0.12-3.21±0.11. A significant difference was observed between the control and treated samples. Control treatment shows higher losses in firmness as compared to all other treated samples. The firmness value in treatment T_3 and T_4 was almost maintained during 15 days of storage. A reduction in firmness values was observed in all treatments during storage. The effect of treatment, days, and their interaction on fruit quality was significant. Firmness showed a decreasing pattern during the 15 days of storage.

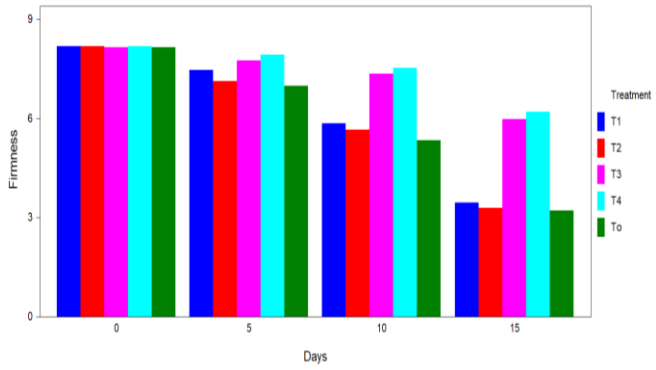

Figure 4. Effect of postharvest treatments on Firmness of banana.

***Total phenolic content*:** The T_0, T_1, T_2, T_3 and T_4 treatments were lies between 162.4±0.01-151.19±0.03. A significant difference was observed between the control and treated samples. Less reduction in total phenolic content (TPC) was observed in T_3 and T_4 during 15 days of storage. The minimum amount of total phenolic content (TPC) was observed in control (140.74±0.03) and the maximum value for TPC was observed in T_4 (151.19±0.04). Total phenolic content (TPC) showed a decreasing pattern during the 15 days of storage. The effect of treatments on the TPC was significant during storage.

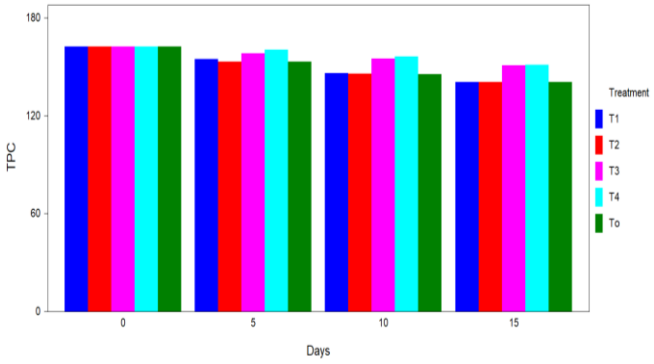

Figure 5. Effect of postharvest treatments on Total Phenolic Content of banana.

Microbial analysis

***Total plate count*:** The mean values of total plate count on treatment and storage of banana fruit have been given in Table. Hence, the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 2.3±0.02-6.2±0.1. A significant difference was observed between the control and treated samples. High reduction in total plate count (TPC) was observed in T_1 and T_4 during 15 days of storage. The minimum amount of total plate count (TPC) was observed in T_1 (3.3±0.2) and the maximum value for TPC was observed in control (6.2±0.1). The effect of treatment, days, and their interaction on the fruit quality was significant. Total plate count (TPC) showed an increasing pattern during the 15 days of storage.

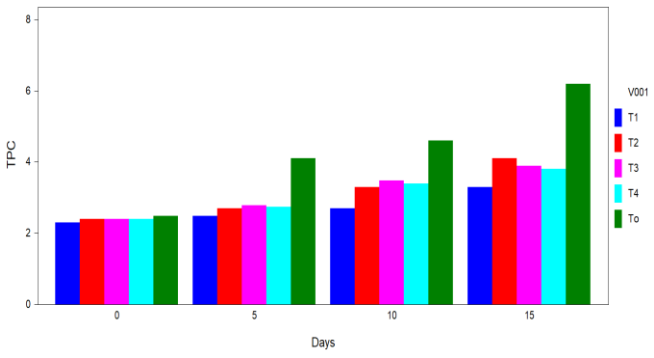

Figure 6. Effect of postharvest treatments on Total Plate Count of banana.

Table 3. Means for total phenolic content (mg GAE/g) of banana fruit during storage.

Treatments	Storage Intervals (Days)				Means
	0 days	5 days	10 days	15 days	
T_0	162.4±0.4	153.1±0.04	145.4±0.2	140.7±0.03	$150.4±8.57^{D}$
T_1	162.4±0.2	154.9±0.1	146.0±0.09	142.8±0.04	$151.0±8.64^{C}$
T_2	162.4±0.4	153.1±0.02	145.9±0.11	140.8±0.01	$150.5±8.48^{D}$
T_3	162.4±0.3	158.2±0.02	155.0±0.03	150.9±0.02	$156.6±4.40^{B}$
T_4	162.4±0.2	160.6±0.03	156.2±0.08	151.2±0.04	$157.6±4.52^{A}$
Means	$162.4±0.1^{A}$	$155.9±0.03^{B}$	$149.4±0.06^{C}$	$144.9±0.01^{D}$	

***Disease Incidence*:** The effect of treatment on the disease incidence of the banana fruit during the storage was significant. The mean values of disease incidence on treatment and storage of banana fruit have been given in Table. Hence, the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 0.00±0.00-26.98±0.02. A significant difference was observed between the control and treated samples. High reduction in disease incidence was observed in T_1 and T_4 during 15 days of storage. The minimum value for disease incidence was observed in T_1 (12.56±0.01) and the maximum value for disease incidence was observed in control (26.98±0.02). An increasing trend in disease incidence was observed in all treatments during storage.

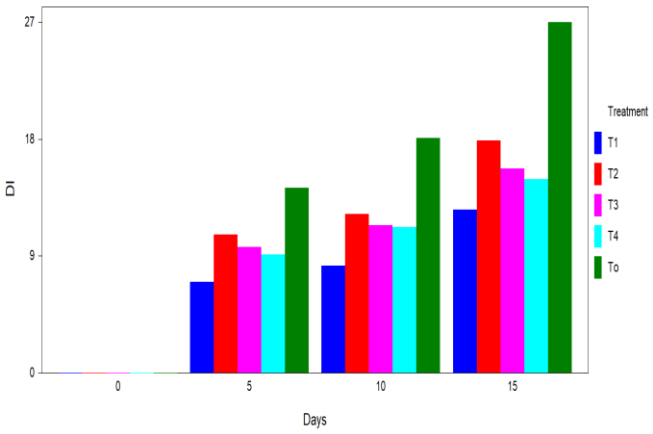

Figure 7. Effect of postharvest treatments on disease incidence (DI) of banana.

***Disease Severity*:** The mean values of disease severity on treatment and storage of banana fruit have been given in Table. Hence the mean values of banana fruit for T_0, T_1, T_2, T_3 and T_4 treatments were lies between 0.00±0.00-25.00±0.03. A significant difference was observed between the control and treated samples. A high reduction in disease severity was observed in T_1 and T_4 during 15 days of storage. The minimum value for disease severity was observed in T_1 (1.02±0.02) and the maximum value for disease severity was observed in control (25.00±0.03). An increasing trend in disease incidence was observed in all treatments during storage. The effect of treatment on the disease severity was significant during storage.

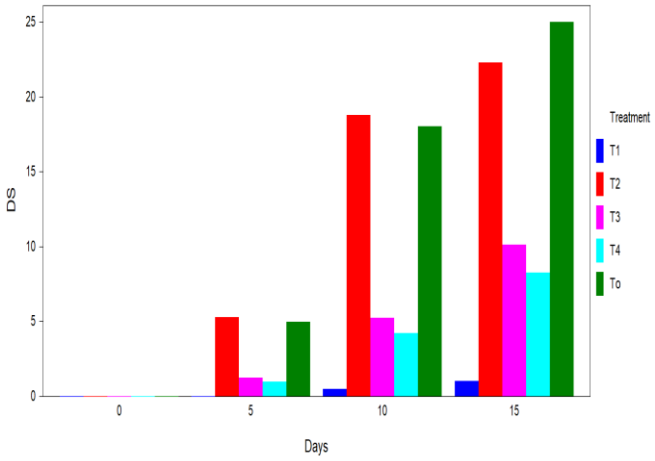

Figure 8. Effect of postharvest treatments on disease severity (DS) of banana.

***Sensory evaluation*:** The sensory evaluation of banana fruit involves assessing various attributes such as texture, taste, color, flavor, and overall acceptability. Sensory evaluation of banana fruit was carried out to determine consumer

Table 4. Means for microbial analysis of banana fruit during storage.

	Treatments	Storage Intervals (Days)				Means
		0 days	5 days	10 days	15 days	
Total plate count	T_0	2.48±0.02	4.1±0.4	4.6±0.4	6.2±0.1	$4.34±1.40^{A}$
	T_1	2.3±0.02	2.48±0.03	2.7±0.1	3.3±0.2	$2.69±0.40^{C}$
	T_2	2.4±0.03	2.7±0.3	3.3±0.1	4.1±0.4	$3.12±0.71^{B}$
	T_3	2.4±0.03	2.78±0.2	3.48±0.3	3.9±0.2	$3.14±0.63^{B}$
	T_4	2.4±0.01	2.74±0.3	3.4±0.4	3.81±0.1	$3.08±0.61^{B}$
	Means	$2.39±0.00^{D}$	$2.96±0.13^{C}$	$3.49±0.15^{B}$	$4.26±0.12^{A}$	
Disease incidence (%)	T_0	0.00±0.00	14.26±0.05	18.08±0.03	26.98±0.02	$14.83±10.15^{A}$
	T_1	0.00±0.00	7.02±0.02	8.24±0.04	12.56±0.01	$6.95±4.71^{E}$
	T_2	0.00±0.00	10.66±0.02	12.24±0.04	17.87±0.02	$10.19±6.75^{B}$
	T_3	0.00±0.00	9.7±0.2	11.37±0.04	15.71±0.01	$9.19 ±6.00^{C}$
	T_4	0.00±0.00	9.1±0.03	11.2±0.1	14.91±0.02	$8.80±5.73^{D}$
	Means	$0.00±0.00^{D}$	$10.14±0.07^{C}$	$12.22±0.02^{B}$	$17.60±0.05^{A}$	
Disease severity (%)	T_0	0.00±0.00	4.98±0.03	18.01±0.01	25.00±0.03	$11.99±10.42^{A}$
	T_1	0.00±0.00	0.00±0.0	0.5±0.4	1.02±0.02	$0.38±0.47^{E}$
	T_2	0.00±0.00	5.27±0.03	18.77±0.05	22.29±0.01	$11.58±9.63^{B}$
	T_3	0.00±0.00	1.25±0.04	5.25±0.02	10.12±0.02	$4.15±4.12^{C}$
	T_4	0.00±0.00	0.98±0.01	4.21±0.04	8.24±0.02	$3.35±3.36^{D}$
	Means	$0.00±0.00^{D}$	$2.49±2.44^{C}$	$9.34±0.16^{B}$	$13.33±0.00^{A}$	

preference on 9 points hedonic scale by my senior students. Fruits of the same maturity level were used to eliminate any bias. The key features of the scale are: 9= Like extremely, 8 = Like very much, 7= Like moderately, 6 = Like slightly, 5= Neither like nor dislike, 4 = Dislike slightly, 3 = Dislike moderately, 2=Dislike very much. 1-Dislike extremely.

***Taste*:** The taste of fresh fruits is a complex sensory experience involving the perception of sweetness, sourness, bitterness, and umami flavors. The taste can be influenced by ripeness, variety, and growing conditions, with different fruit varieties displaying distinct taste profiles. Mean values for the taste of banana were ranged from 4.9±0.2 to 7.26±0.5. The highest score for taste was recorded in treatment T_3 and T_4, treated with highest concentrations of chemicals that proved to be effective in maintaining quality attributes. The least score was recorded in control treatment.

***Flavor*:** Flavor encompasses the combined sensations of taste and aroma, with enhanced natural sweetness. The flavor and taste properties of fresh fruits are essential quality factors that contribute to their overall appeal and shelf life. Mean values for the flavor of banana were ranged from 4.3±0.3 to 7.32±0.6. The highest flavor score was recorded in treatment T_3 and T_4, treated with the highest concentrations of calcium chloride that proved to be effective in maintaining quality attributes of banana.

***Texture*:** Textural stability of fresh fruit is an important quality factor and a marker of harvest maturity. Assessing the texture of fruits is crucial for determining their postharvest shelf life. The textural score by judging panel revealed a downward trend. Mean values for the texture of banana were ranged from 4.2±0.4 to 8.46±0.2. The highest textural score was recorded in treatment T_4. In the treated samples, the textural score decreased gradually, but it decreased quickly in the control samples.

Table 5. Means for organoleptic quality of banana fruit during storage.

Treatment	Day	Taste	Flavor	Texture	Overall Acceptability
T_0	**0**	6.4±0.5	5.51±0.1	5.09±0.3	5.38±0.2
	5	5.9±0.2	5.1±0.4	4.8±0.1	5.0±0.3
	10	5.4±0.6	4.7±0.1	4.5±0.5	4.6±0.1
	15	4.9±0.2	4.3±0.3	4.2±0.4	4.2±0.4
T_1	**0**	7.22±0.3	7.28±0.1	8.25±0.5	7.49±0.2
	5	7.0±0.1	7.0±0.3	8.1±0.5	7.3±0.4
	10	6.9±0.1	6.7±0.2	8.0±0.6	7.1±0.6
	15	6.6±0.4	6.3±0.3	7.8±0.1	6.7±0.2
T_2	**0**	7.21±0.4	7.25±0.1	8.18±0.3	7.50±0.3
	5	6.9±0.7	7.0±0.1	8.0±0.4	7.3±0.1
	10	6.8±0.3	6.6±0.3	7.8±0.3	7.0±0.1
	15	6.5±0.4	6.2±0.4	7.5±0.3	6.5±0.6
T_3	**0**	6.25±0.8	7.3±0.2	8.4±0.2	7.5±0.1
	5	7.12±0.5	7.0±0.1	8.2±0.4	7.3±0.7
	10	6.9±0.2	6.7±0.1	8.0±0.6	7.0±0.3
	15	6.7±0.3	6.4±0.7	7.8±0.3	6.7±0.5
T_4	**0**	7.26±0.5	7.32±0.6	8.46±0.2	7.83±0.2
	5	7.15±0.7	7.1±0.4	8.3±0.1	7.6±0.3
	10	7±0.3	6.8±0.1	8.1±0.3	7.3±0.1
	15	6.8±0.5	6.5±0.2	7.8±0.1	7.0±0.3

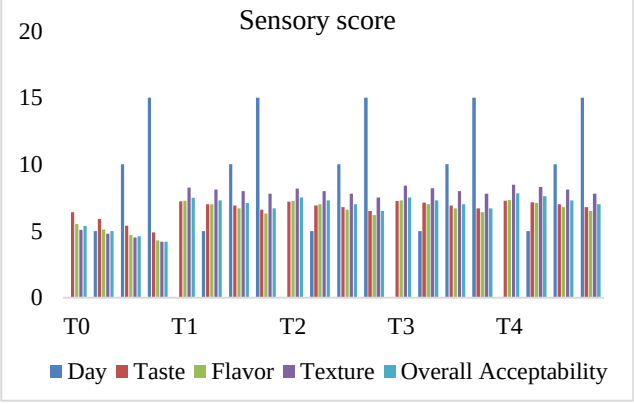

Figure 9. Effect of postharvest treatment on organoleptic quality of banana.

***Overall acceptability*:** Overall acceptability is the combined assessment of all sensory attributes, where enhanced color, flavor, taste, and texture result in higher consumer satisfaction and preference. Mean values for the overall acceptability of banana were ranged from 4.2±0.4 to 7.83±0.2. The highest score for overall acceptability was recorded in treatment T_4. The treated sample received the greatest overall acceptability score and was maintained throughout storage, while the control group received the lowest marks.

DISCUSSION

The ideas presented make up the focus of this research and present important insights in the field of banana postharvest management and its effect on banana's quality and shelf life. In this study, the overall trends of the external and inner qualities of banana and their general tendency toward ripening observed during the time of investigation were discussed. The pH content of the study are in line with those found by Zomo *et al.* (2014) who conducted research to assess the effects of various postharvest techniques on the chemical characteristics of banana fruits and their shelf life. It was

observed that various postharvest treatments had a significant impact on the chemical qualities of bananas. The result showed that on the ninth day of storage, fruit treated with 30ppm benzyl adenine, and 150 ppm of gibberellic acid had a significantly lower pH value. Conversely, the control group had higher pH values. The constant decrease in acidity that occurs during ripening could be the cause of the pH rise. Similar results were reported by Kaka *et al.* (2019) who carried out a study to determine the impact of hot water treatments and storage duration on the quality characteristics of bananas. The result showed that the hot water treatment and storage time had a major effect on the quality characteristics of banana fruit. The bananas with the lowest values for total soluble solids, pulp pH, total sugar content, and decay incidence were those that had 50°C hot water dip treatment. It was also observed that pulp pH and total soluble solids increased with the number of storage days.

The titratable acidity content of the study are in line with those found by Vilaplana *et al.* (2018) who carried out a study to determine whether hot water dips were useful. After 21 days of cold storage, they found that the TA values in fruit treated with imazalil and hot water dips, such as 40°C for twenty minutes and 50°C for 1 minute, were much lower than those in fruit that was not treated. The finding showed that banana ripening processes were delayed when hot water at 40°C for 20 minutes and 50°C for one minute was applied. Ernesto *et al.* (2017) also documented similar results for titratable acidity of banana. They conducted a study to check the impact of $CaCl_2$ and hot water on banana and mango. The finding demonstrated that the TSS content steadily dropped with the addition of 3% calcium treatment and at 55°C hot water, while TA increased dramatically throughout the course of the study. The fast oxidation of ascorbic acid was also reported to be delayed by the $CaCl_2$ concentrations, according to these researchers.

The total soluble solid content of current study is in line with those documented by Al-Qurashi and Awad (2019) who conducted a study to determine the impact of calcium chloride on quality attributes and ripening process of banana. The result showed that the apart from their minor effects on peel color and browning, 2% calcium chloride ($CaCl_2$) delayed the ripening of bananas. This was evident through increased firmness and titratable acidity, as well as reduced Total Soluble Solids (TSS) content and TSS/TA ratio compared to the control. These outcomes are likely due to the general preservative properties of $CaCl_2$, which act as inhibitors of ripening and senescence. The mechanisms possibly include reducing respiration rate, ethylene production, and oxidative processes. Aghofack-Nguemezi and Tafre-Phounzong (2021) also found that the total soluble solids (TSS) content increased in all bananas during storage. However, the increase was slower in fruit treated with 2% and 4% calcium chloride ($CaCl_2$) compared to control bananas. The result showed that the increase in soluble and reducing sugars in all treatments was due to the degradation of starch and other polysaccharides into soluble sugars in the pulp, facilitated by the action of conversion enzymes.

The firmness content of this study are conformed with those reported by the Vilaplana *et al.* (2018) who observed that during 14 days of storage, fruit treated at 40°C for 20 minutes exhibited considerably greater values than other treatments. The firmness of the organic banana deteriorated during the postharvest period. The fruit treated at 40°C for 20 minutes was the following to be stiffer than the organic bananas treated with imazalil after 21 days at 13°C. The controls (untreated) and hot water treatments softened quickly over the 28-day shelf life, most likely as a result of the high relative humidity and temperature selected for this conservation period. Varit and Songsin (2011) also observed that the physiology and quality of "Kluai Khai" bananas are affected by hot water treatments. The result showed that compared to fruit that had been treated with hot water, the untreated control's fruit firmness reduced more quickly with storage. The best hot water technique for delaying softening was 50°C for ten minutes. While other hot water treated fruit softened to the control level after 6 days of storage, this fruit remained firm for 9 days and softened after 3 days.

The bananas were also subjected to phytochemical analysis. These findings are coinciding with results reported by Sripong *et al.* (2020) who investigated the effects of propolis extract, prochloraz, and paraffin wax alone and in combination on preventing crown rot and preserving banana quality. The finding demonstrated that the banana crown's total phenolic content tended to drop over storage. The samples treated with paraffin alone and paraffin with propolis had the highest levels of total phenolic. On the other hand, coating with 250 ppm of prochloraz or propolis alone demonstrated a low total phenolic concentration comparable to the uncoated treatment. Minh (2022) investigated the efficiency of calcium on physical and chemical attributes of banana while stored. He also observed a pattern of declining total phenolic content throughout storage, with the control banana showing a notable decline and the 3% $CaCl_2$ treated banana showing a minor decline by the 28^{th} day of storage. The use of $CaCl_2$ slowed down the buildup of H_2O_2 and enhanced the activity of antioxidant enzymes that is good for banana fruit during storage.

The total plate count of this study is conformed with those reported by Tchamba *et al.* (2023) who investigated the impact of calcium and glycerol on physicochemical attributes

of banana. The result showed that as compared to the control, the banana's rate of decay was lowered by the 4% $CaCl_2$ treatment. The antibacterial activity of $CaCl_2$ may account for decreased rate of decay of fruit following its application. Rocha *et al.* (2011) also carried out a study to check the effect of different chemical treatments in controlled environment. The findings indicated that the application of carrageenan to fresh-cut bananas does not impact microbiological growth after edible coating. However, when combined with an earlier chemical treatment involving 1% calcium chloride, ascorbic acid, and L-cysteine, it has an antimicrobial effect, particularly on fresh-cut bananas during 9 days of storage.

The disease index of current study are coinciding with results reported by Mulagund *et al.* (2015) carried out a study to check the impact of different chemical and hot water treatments on the quality attributes of banana. The result showed that producers can optimize yield, enhance quality, and extend post-harvest life while minimizing physiological weight loss and disease occurrence by combining pre-harvest sprays with post-harvest fruit dipping with GA_3 (0.01) and thiabendazole (0.02%) or 0.1% $CaCl_2$ and thiabendazole (0.02%). The fruits that were sprayed with GA_3 along with Thiabendazole achieved the longest storage period of 18 days. Another study conducted by Kamal *et al.* (2019) also reported similar results. They conducted a study to envisage the impact of hot water and packaging on the quality attributes and biochemical changes in banana after harvest. The result showed that as the investigation carried on, more changes in firmness and color were discovered. Banana varieties and postharvest treatments affect weight loss and disease incidence. During 12 days of storage, garlic extract combined with perforated polythene was determined to be the most effective postharvest treatment for bananas in controlling disease incidence.

The findings comply with the results found by Nath *et al.* (2015) who conducted a study to check the impact of different fungicides on banana. The result showed that the most popular and readily available fungicide, propiconazole (0.025%) completely reduced the incidence of finger rot disease in the field and fruit rot disease in the postharvest. Given that both diseases are caused by L. theobromae, these results are significant in the current context. Similar results were documented by Akter *et al.* (2013). They observed that postharvest treatments had a significant impact on the surface disease of bananas in every variety. The severity of the illness was significantly reduced by postharvest treatments. The result showed that modified atmosphere packaging with $KMnO_4$ has proven to be an effective strategy for preserving the quality and extending the shelf life of bananas during 12 days of storage. The extended shelf life of bananas treated as previously described may be attributed to the slower alterations in their chemical composition.

The organoleptic score complies with results given by Sahay *et al.* (2017) who showed that under all the wrapping materials, the organoleptic assessment score gradually increased before declining as the storage period increased. The softness, flavor, TSS increase, color development, and acidity decrease were the primary causes of the initial increase in organoleptic score. After 16 days at room temperature, fruits kept in a plastic bag with 4% $CaCl_2$ received a high organoleptic score. It was demonstrated that applying $CaCl_2$ 4% with polyethylene bag or $CaCl_2$ 2% with polyethylene bag extended the shelf life of banana fruits, decreased spoiling, and maintained marketability with a fair organic score. The results of the current study are like this previous study.

***Conclusion*:** This research focused on evaluating the effectiveness of postharvest treatments in maintaining the quality and extending the shelf life of green bananas during storage. The study demonstrated that the application of 4% calcium chloride was highly effective in preserving the nutritional and sensory attributes of the bananas over an extended period. This treatment significantly delayed spoilage, proving to be an economical and practical alternative to more conventional methods, while minimizing the use of harsh chemicals. Overall, this research contributes to the field of food preservation and post-harvest technology by offering insights into effective, sustainable approaches for enhancing banana quality and reducing post-harvest losses. However, for future research, studies that focus on the additional parameters which include respiration rate, ethylene production, and other physiochemical changes should be conducted. Studying these aspects, as well as other treatment concentrations and their interaction with a wider range of storage conditions, would give more comprehensive information on the quality shifts of fruits and vegetables with different postharvest treatments.

***Authors contributions statement*:** Tamseen Fatima and Ali Hassan designed the study plan. Tamseen Fatima and Fatima Waheed performed all the analysis and recorded the data. Ali Hassan and Fatima Waheed analyzed the results. Tamseen Fatima wrote the original draft. All the authors critically reviewed the final manuscript and approved it.

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***Code availability*:** The code supporting the findings of this study is available from the corresponding author upon reasonable request.

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